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Biodiversity assessment in Western Mediterranean marine protected areas (MPAs): Porifera of *Posidonia oceanica* meadows (Asinara Island MPA) and marine caves (Capo Caccia–Isola Piana MPA) of Sardinia

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Abstract

This paper focuses on a faunistic inventory and the biogeographic pattern of Sardinian Porifera in a scarcely investigated Italian sea belonging to the Eastern Algero-Provençal Basin. The composition and structure of sponge fauna were studied in two priority habitats in two Marine Protected Areas (MPAs) of the North-Western Sardinian Sea. Shallow-water surveys investigated *Posidonia oceanica* meadows at five sites in the Asinara Island MPA and three karstic submerged caves in the Capo Caccia–Isola Piana MPA. The annotated checklist shows notably high values of taxonomic richness, confirming that *P. oceanica* meadows and karstic caves are key habitats for Porifera assemblages. Indeed, the sponge taxa recorded ($n = 77$) with 59 cave-dwelling and 45 taxa in seagrass meadows represent over 10% of the total Mediterranean sponge fauna, despite the small areas investigated, restricted biotopes and low sampling effort. This suggests that species richness is underestimated in circum-Sardinia seas. Internationally protected species ($n = 6$), rare species ($n = 5$) and Mediterranean endemic species ($n = 14$) were recorded. Previously investigated *Posidonia* meadows and caves share comparable values of species richness and endemism with the Sardinian biotopes. The geographic range of species indicates that the biogeographic affinity of the NW Sardinian Sea sponge fauna is dominated by Atlanto-Mediterranean species. The three caves harbour a notably homogeneous sponge community, as indicated by the ca. 50% of shared species and high similarity index ($> 83\%$). By contrast, the composition varies markedly among the five *Posidonia* meadows, which share only five species and display similarity values ranging ca. 20–60%. Unexpectedly when comparing these contrasting biotopes, faunal similarity is relatively low ($< 40\%$ shared species); indeed, *Posidonia* meadows harbour a notable number of cave-dwelling species in intermatte shaded microhabitats.

Keywords: Priority habitats, Italian sponge fauna, annotated checklist, composition/species richness/endemism, biogeography

Introduction

The Mediterranean Sea is one of the world's priority hotspots for conservation and is home to a wealth of endemic sponge species (Coll et al. 2010; Pansini et al. 2011; Pronzato et al. 2012). Since ancient times, this semi-enclosed sea has been affected by human activity, and today its biodiversity is greatly endangered by habitat destruction, the overexploitation of bioresources and climate change (Médail & Quézel 1999; Halpern et al. 2008; Costello et al. 2010; Sala et al. 2012). In 1992 the European community established a list of habitats and

species in need of protection, and more recently a list of 11 descriptors was selected as the basis for the assessment of Good Environmental Status (GES; Habitat Directive 1992, 2008; UNEP-MAP-RAC/SPA 2015). International conventions mandate conservation of these biotopes, which must be closely monitored, particularly in protected areas.

Major concerns have been raised with regard to some key taxa, such as Mediterranean Porifera, especially as massive pandemics have brought entire populations of some sponge species to the brink of

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extinction during the last three decades (Gaino & Pronzato 1991; Gaino et al. 1992; Rizzello et al. 1997; Pronzato 1999; Cerrano et al. 2000; Manconi et al. 2001; Pronzato & Manconi 2008; Pronzato et al. 2012; Di Camillo et al. 2013). Moreover, shallow benthic communities have suffered a loss of structural complexity, mainly due to the marked decrease in engineering organisms, mostly sponges (Bertolino et al. 2016).

The Mediterranean sponge fauna has been amply studied and consists of approximately 720 species (Pansini & Longo 2003; Pansini et al. 2011; Van Soest et al. 2018; Bertolino & Pronzato, personal databases). By contrast, the benthic fauna of some Mediterranean sub-basins has not been thoroughly investigated, such as that of several North African sub-basins, the Sardinia Sea and the Corsica Sea, despite the central position of these areas in the Mediterranean and the influence of Atlantic inflow along their coasts. Historical data sets, mainly on marine protected areas (MPAs), are fundamental to understanding the accelerating changes occurring over time and space in the Mediterranean Sea.

The main aim of this paper was to contribute to basic knowledge of the Porifera fauna in two north-western Sardinian MPAs (Eastern Algero-Provençal Basin) by studying the composition and diversity of sponge assemblages in two priority habitats. The homogeneity vs. heterogeneity of taxonomic structure were investigated and compared within and among sponge assemblages in two contrasting shallow-water biotopes. In accordance with the EU guidelines, we focused on two biotopes of conservation interest, *Posidonia oceanica* (L.) Delile (1813) meadows and submerged marine caves, and used Porifera assemblages as a model taxon in terms of five descriptors, i.e. taxonomic composition, species richness, endemism, richness of species of conservation value, and richness of rare species. The biogeographic affinity of the north-western Sardinian sponge fauna was also assessed on the basis of the geographic range of recorded species.

Materials and methods

Two priority habitats were investigated and censuses of sponge fauna were conducted in shallow water along the Northern Sardinian Sea coast (north-western Sardinia Island, Eastern Algero-Provençal Basin, Western Mediterranean Sea): i.e. at five sites of *P. oceanica* meadows along the southern coast of the Asinara Island MPA (2–6 m depth; Asinara Gulf; Figure 1A) and three submerged karstic caves (Bisbe, Falco, Galatea) at the Punta Giglio Promontory, a rocky limestone promontory dating back to the Mesozoic Era within

the Capo Caccia-Isola Piana MPA (3–9 m depth; Figure 1B). These biotopes are impacted by several tourist activities, such as bathing, snorkelling, scuba diving and recreational fishing and boating, as well as by professional fishing and environmental alteration and pollution.

Sampling protocol

Sponges were photographed *in vivo*; representative fragments were then collected by means of SCUBA diving (two surveys per cave) and snorkelling (two surveys per site) along randomly selected transects in each biotope, preserved (in 95% ethanol or dried) and registered in a reference collection (> 400 specimens).

Macroscopic analysis of morphology was carried out on each sample by means of light microscopy (LM, stereo-microscope) and examination of > 300 *in vivo* photographs. Specimens were dissected in order to obtain representative fragments to be processed for the preparation of slides of cleaned skeletal networks and spicules in accordance with standard methods (Rützler 1978). Taxonomic identification was carried out on the basis of morphological diagnostic macro- and micro-traits on > 400 LM slides. The taxonomic status of species was determined in accordance with Systema Porifera (Hooper & Van Soest 2002), Fauna d'Italia (Pansini et al. 2011), and the World Porifera Database (WPD) (Van Soest et al. 2018). Species were considered rare when fewer than 10 published reports of their presence in the Mediterranean Sea were available.

Statistical analysis

Multivariate analysis and non-metric multidimensional scaling (nMDS) based on the Bray–Curtis similarity index for paired groups (unweighted pair group method with arithmetic mean, UPGMA) were applied to a data set of the presence/absence of the sponge species in order to evaluate the relationships of sponge species composition among: (i) the five *Posidonia* meadows; (ii) the three karstic caves; and (iii) *P. oceanica* vs. caves. nMDS was carried out on a data set of presence/absence by sampling site to evaluate significant differences in sponge composition in the two priority habitats (caves and *Posidonia*). The significant differences were assessed by means of the one-way analysis of similarities (ANOSIM) test; similarity matrices were based on the Bray–Curtis similarity index, and probability percentages lower than 3% were considered significant (Clarke & Warwick 2001). Statistical analyses were

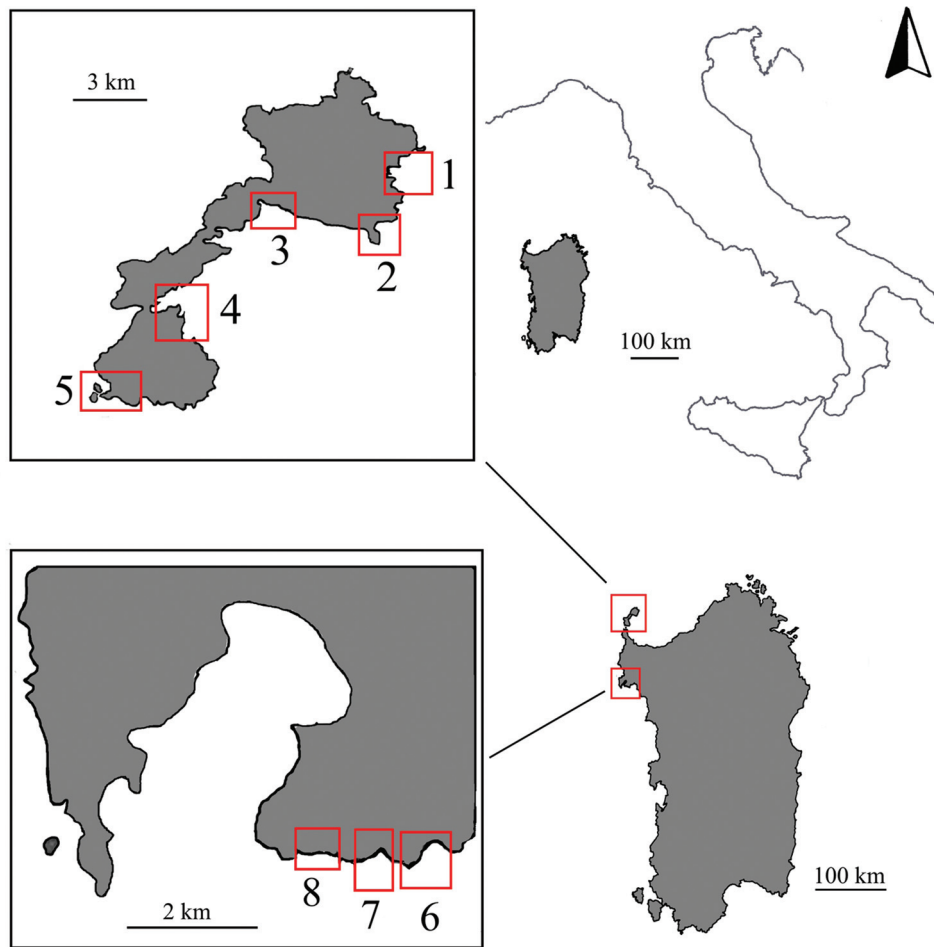


Figure 1. Study area in the two selected Sardinian Marine Protected Areas (MPAs) in the eastern Algero-Provençal Basin, Western Mediterranean (eight sampling areas within the boxes). Five *Posidonia* meadows at the Asinara Island MPA (box, top, left). Three karstic submerged caves (Galatea = 6, Falco = 7, Bisbe = 8) at the Capo Caccia-Isola Piana MPA (box, bottom, left).

performed by means of PRIMER for the nMDS and ANOSIM test. PAST (Palaeontological Statistics, v. 3.14) software was used to assess Bray–Curtis similarity (Hammer et al. 2001). Only taxa identified at the species level were included in statistical analyses.

Results

The annotated checklist reports a total of 77 taxa (Table I), 69 of which were identified at the species level (> 90% of the ca. 400 samples) despite the small areas investigated, restricted biotopes and low sampling effort. Some specimens ($n = 8$) remained undetermined, i.e. they were identified at the genus level, since they were in too poor a condition to allow more precise identification.

Taxonomic richness in caves

Galatea Cave (site 6) was seen to harbour 42 species, plus five taxa identified at the genus level, belonging to 38 genera, 28 families and 15 orders (Table I). Endemicity was ca. 16.6%, with seven Mediterranean endemics. Falco Cave (site 7) harboured 35 species, plus three taxa identified at the genus level, belonging to 29 genera, 22 families and 13 orders (Table I). Endemicity was ca. 17.1%, with six Mediterranean endemics. Bisbe Cave (site 8) harboured 28 species, plus seven taxa identified at the genus level, belonging to 26 genera, 20 families and 14 orders (Table I). Endemicity was ca. 21.4% with six Mediterranean endemic species.

In all, 51 species, plus eight taxa identified at the genus level, were recorded in the three submerged karstic caves, with 24 shared species. Endemicity is ca. 19.6% with 10 Mediterranean endemics. Atlanto-Mediterranean species are dominant ($n = 30$), and there were 11 cosmopolitans.

Table I. Annotated checklist of sponge species (Porifera) recorded in priority habitats of the two Sardinia Island marine protected areas (MPAs; Northern Sardinian Sea, Algero-Provençal Basin, Western Mediterranean). Sampled sites are indicated by numbers: Asinara Island MPA, *Posidonia* meadows 1–5 (see Figure 1); Capo Caccia–Isola Piana MPA karstic submerged caves 6–8 (see Figure 1). E = Mediterranean Endemics; AM = Atlanto-Mediterranean; C = cosmopolitan. * P = Species protected by international conventions; R = rare species (less than 10 records). *The geographic range of species is our best attempt at agreement among the World Porifera Database (WPD; Soest et al. 2018); Fauna d'Italia, Porifera I (Pansini et al. 2011) and the unpublished database of Gustavo Pulitzer-Finali (1999), 71 volumes manuscript, preserved in the library of DiSTAV, Genoa University, Italy. As for “cosmopolitan species”, they must be considered with caution, several records being “inaccurate” (*sensu* WPD).

No.	Species	<i>Posidonia</i>					Caves			Geographic range	Status
		1	2	3	4	5	6	7	8		
	CALCAREA Bowerbank, 1864										
	Clathrinida Hartman, 1958										
	Clathrinidae Minchin, 1900										
	<i>Clathrina</i> Gray, 1867										
1.	<i>Clathrina clathrus</i> (Schmidt, 1864)			+			+	+	+	E	
2.	<i>Clathrina rubra</i> Sarà, 1958		+	+						AM	R8
	Leucaltidae Dendy & Row, 1913										
	<i>Ascandra</i> Haeckel, 1872										
3.	<i>Ascandra contorta</i> (Bowerbank, 1866)						+			AM	
	Leucosolenida Hartman, 1958										
	Sycettidae Dendy, 1893										
	<i>Sycon</i> Risso, 1827										
4.	<i>Sycon</i> sp.				+	+			+		
	Lithonida Vacelet, 1981										
	Baerida Borojevic, Boury-Esnault & Vacelet, 2000										
	<i>Petrobiona</i> Vacelet & Lévi, 1958										
5.	<i>Petrobiona massiliiana</i> Vacelet & Lévi, 1958						+	+	+	E	P
	HOMOSCLEROMORPHA Bergquist, 1978										
	Homosclerophorida Dendy, 1905										
	Oscarellidae Lendenfeld, 1887										
	<i>Oscarella</i> Vosmaer, 1884										
6.	<i>Oscarella lobularis</i> (Schmidt, 1862)	+					+	+	+	C	
	Plakinidae Schulze, 1880										
	<i>Corticium</i> Schmidt, 1862										
7.	<i>Corticium candelabrum</i> Schmidt, 1862				+		+			AM	
	<i>Plakina</i> Schulze, 1880										
8.	<i>Plakina trilopha</i> Schulze, 1880				+					C	
	DEMOSPONGIAE Sollas, 1885										
	Tetractinellida Marshall, 1876										
	Ancorinidae Schmidt, 1870										
	<i>Stelletta</i> Schmidt, 1862										
9.	<i>Stelletta lactea</i> Carter, 1871						+	+		AM	
10.	<i>Stelletta dorsigera</i> Schmidt, 1862			+						E	
	<i>Jaspis</i> Gray, 1867										
11.	<i>Jaspis johnstonii</i> (Schmidt, 1862)			+			+			AM	
	<i>Dercitus</i> Gray, 1867										
12.	<i>Dercitus (Stoebea) dissimilis</i> (Sarà, 1959)						+			E	R3
	Geodiidae Gray, 1867										
	<i>Erylus</i> Gray, 1867			+			+			AM	
13.	<i>Erylus discophorus</i> (Schmidt, 1862)										
	<i>Penares</i> Gray, 1867										
14.	<i>Penares euastrum</i> (Schmidt, 1868)						+	+	+	AM	
	Thoosidae Cockerell, 1925										
	<i>Alectona</i> Carter, 1879						+	+		AM	
15.	<i>Alectona millari</i> Carter, 1879										
	Clionaida Morrow & Cárdenas, 2015										
	Clionaidae d'Orbigny, 1851										
	<i>Cliona</i> Grant, 1826										
16.	<i>Cliona schmidtii</i> (Ridley, 1881)						+			C	
17.	<i>Cliona viridis</i> (Schmidt, 1862)	+		+	+		+	+	+	C	

(Continued)

Table I. (Continued).

No.	Species	Posidonia					Caves			Geographic range	Status
		1	2	3	4	5	6	7	8		
18.	<i>Cliona</i> sp. 1								+		
19.	<i>Cliona</i> sp. 2						+				
Spirastrellidae Ridley & Dendy, 1886											
	<i>Diplastrella</i> Topsent, 1918										
20.	<i>Diplastrella bistellata</i> (Schmidt, 1862)	+			+		+	+	+	AM	
	<i>Spirastrella</i> Schmidt, 1868										
21.	<i>Spirastrella cunctatrix</i> Schmidt, 1868	+	+	+	+	+	+	+	+	C	
Suberitida Chombard & Boury-Esnault, 1999 Suberitidae Schmidt, 1870											
	<i>Aaptos</i> Gray, 1867										
22.	<i>Aaptos aaptos</i> (Schmidt, 1864)	+		+	+		+	+	+	C	
	<i>Terpios</i> Duchassaing & Michelotti, 1864										
23.	<i>Terpios gelatinosus</i> (Bowerbank, 1866)			+			+	+	+	C	
Halichondriidae Gray, 1867											
	<i>Halichondria</i> Fleming, 1828										
24.	<i>Halichondria</i> (<i>Halichondria</i>) <i>genitrix</i> (Schmidt, 1870)							+		AM	
Agelasida Hartman, 1980											
Hymenhabdiidae Morrow, Picton, Erpenbeck, Boury-Esnault, Maggs & Allcock, 2012											
	<i>Prosuberites</i> Topsent, 1893										
25.	<i>Prosuberites</i> sp.								+		
Tethyida Morrow & Cárdenas, 2015											
Tethyidae Gray, 1848											
	<i>Tethya</i> Lamarck, 1815										
26.	<i>Tethya aurantium</i> (Pallas, 1766)			+	+					AM	P
27.	<i>Tethya citrina</i> Sarà & Melone, 1965			+						AM	P
Timeidae Topsent, 1928											
	<i>Timea</i> Gray, 1867										
28.	<i>Timea geministellata</i> Pulitzer-Finali, 1978				+					E	
Chondrosiida Boury-Esnault & Lopès, 1985 Chondrosiidae Schulze, 1877											
	<i>Chondrosia</i> Nardo, 1847										
29.	<i>Chondrosia reniformis</i> Nardo, 1847			+	+	+	+			C	
Chondrillida Redmond, Morrow, Thacker, Diaz, Boury-Esnault, Cardenas, Hajdu, Lobo-Hajdu, Picton, Pomponi, Kayal & Collins, 2013											
Chondrillidae Gray, 1872											
	<i>Chondrilla</i> Schmidt, 1862										
30.	<i>Chondrilla nucula</i> Schmidt, 1862	+	+	+	+	+				C	
Axinellida Lévi, 1953											
Raspailiidae Nardo, 1833											
	<i>Eurypon</i> Gray, 1867										
31.	<i>Eurypon major</i> Sarà & Siribelli, 1960							+		AM	
Axinellidae Carter, 1875											
	<i>Axinella</i> Schmidt, 1862										
32.	<i>Axinella damicornis</i> (Esper, 1794)						+	+	+	AM	
33.	<i>Axinella verrucosa</i> (Esper, 1794)						+			AM	
Biemnida Morrow, 2013											
Rhabderemiidae Topsent, 1928											
	<i>Rhabderemia</i> Topsent, 1890										
34.	<i>Rhabderemia minutula</i> (Carter, 1876)						+	+		AM	
Poecilosclerida Topsent, 1928 Tedaniidae Ridley & Dendy, 1886											
	<i>Tedania</i> Gray, 1867										
35.	<i>Tedania</i> (<i>Tedania</i>) <i>anhelans</i> (Vio in Olivi, 1792)				+					AM	
Chondropsidae Carter, 1886											
	<i>Batzella</i> Topsent, 1893										
36.	<i>Batzella inops</i> (Topsent, 1891)					+	+			AM	
Crambeidae Lévi, 1963											
	<i>Crambe</i> Vosmaer, 1880										
37.	<i>Crambe crambe</i> (Schmidt, 1862)	+	+	+	+	+	+	+	+	C	

(Continued)

Table I. (Continued).

No.	Species	Posidonia					Caves			Geographic range	Status
		1	2	3	4	5	6	7	8		
	Crellidae Dendy, 1922										
	<i>Crella</i> Gray, 1867										
38.	<i>Crella</i> sp.						+	+	+		
	Hymedesmiidae Topsent, 1928										
	<i>Hemimyscale</i> Burton, 1934										
39.	<i>Hemimyscale columella</i> (Bowerbank, 1874)		+	+			+	+		AM	
	<i>Hymedesmia</i> Bowerbank, 1864										
40.	<i>Hymedesmia</i> (<i>Hymedesmia</i>) <i>pansa</i> Bowerbank, 1882			+						AM	
41.	<i>Hymedesmia</i> (<i>Hymedesmia</i>) <i>peachii</i> Bowerbank, 1882			+						AM	
42.	<i>Hymedesmia</i> (<i>Hymedesmia</i>) sp.						+		+		
	<i>Phorbas</i> Duchassaing & Michelotti, 1864										
43.	<i>Phorbas dives</i> (Topsent, 1891)							+		AM	
44.	<i>Phorbas fictitius</i> (Bowerbank, 1866)			+	+	+	+			AM	
45.	<i>Phorbas tenacior</i> (Topsent, 1925)	+		+			+	+	+	AM	
	Bubarida Topsent, 1894										
	Dictyonellidae Van Soest, Diaz & Pomponi, 1990										
	<i>Acanthella</i> Schmidt, 1862										
46.	<i>Acanthella acuta</i> Schmidt, 1862						+	+	+	AM	
	<i>Dictyonella</i> Schmidt, 1868										
47.	<i>Dictyonella</i> sp.						+	+	+		
	Agelasida Hartman, 1980										
	Agelasidae Verrill, 1907										
	<i>Agelas</i> Duchassaing & Michelotti, 1864										
48.	<i>Agelas oroides</i> (Schmidt, 1864)						+	+	+	E	
	Haplosclerida Topsent, 1928										
	Chalinidae Gray, 1867										
	<i>Chalinula</i> Schmidt, 1868										
49.	<i>Chalinula limbata</i> (Montagu, 1814)			+						AM	
50.	<i>Chalinula renieroides</i> Schmidt, 1868				+					AM	
	<i>Dendroxea</i> Griessinger, 1971										
51.	<i>Dendroxea lenis</i> (Topsent, 1892)						+	+	+	AM	
	<i>Haliclona</i> Grant, 1841										
52.	<i>Haliclona</i> (<i>Halichoclona</i>) <i>fulva</i> (Topsent, 1893)							+		AM	
53.	<i>Haliclona</i> (<i>Reniera</i>) <i>cratera</i> (Schmidt, 1862)							+		AM	
54.	<i>Haliclona</i> (<i>Soestella</i>) <i>mucosa</i> (Griessinger, 1971)						+	+	+	AM	
55.	<i>Haliclona</i> sp.						+	+	+		
	Niphatidae van Soest, 1980										
	<i>Pachychalina</i> Schmidt, 1868										
56.	<i>Pachychalina rustica</i> Schmidt, 1868	+			+					E	R7
	Petrosiidae Van Soest, 1980										
	<i>Petrosia</i> Vosmaer, 1885										
57.	<i>Petrosia</i> (<i>Petrosia</i>) <i>ficiformis</i> (Poiret, 1789)	+			+		+	+	+	AM	
	Dendroceratida Minchin, 1900										
	Darwinellidae Merejkowsky, 1879										
	<i>Aplysilla</i> Schulze, 1878										
58.	<i>Aplysilla rosea</i> (Barrois, 1876)			+			+			C	
	Dictyoceratida Minchin, 1900										
	Dysideidae Gray, 1867										
	<i>Dysidea</i> Johnston, 1842										
59.	<i>Dysidea avara</i> (Schmidt, 1862)	+			+		+	+	+	C	
60.	<i>Dysidea fragilis</i> (Montagu, 1818)						+	+	+	C	
61.	<i>Dysidea incrustans</i> (Schmidt, 1862)			+			+			E	
	<i>Pleraplysilla</i> Topsent, 1905										
62.	<i>Pleraplysilla spinifera</i> (Schulze, 1879)						+	+	+	AM	
	Irciniidae Gray, 1867										
	<i>Ircinia</i> Nardo, 1833										
63.	<i>Ircinia oros</i> (Schmidt, 1864)	+	+	+			+	+	+	E	

(Continued)

Table I. (Continued).

No.	Species	Posidonia					Caves			Geographic range	Status
		1	2	3	4	5	6	7	8		
64.	<i>Ircinia retidermata</i> Pulitzer-Finali & Pronzato, 1981	+	+	+	+			+		E	R3
65.	<i>Ircinia variabilis</i> (Schmidt, 1862)	+	+	+	+	+	+	+	+	AM	
	<i>Sarcotragus</i> Schmidt, 1862										
66.	<i>Sarcotragus fasciculatus</i> (Pallas, 1766)				+					AM	
67.	<i>Sarcotragus spinosulus</i> Schmidt, 1862	+	+	+	+					AM	
Spongiidae Gray, 1867											
	<i>Hippospongia</i> Schulze, 1879										
	<i>Hippospongia communis</i> (Lamarck, 1813)										
68.	<i>Spongia</i> Linnaeus, 1759	+		+	+					E	P
69.	<i>Spongia (Spongia) lamella</i> (Schulze, 1879)						+	+	+	E	P
70.	<i>Spongia (Spongia) nitens</i> (Schmidt, 1862)					+		+	+	AM	
71.	<i>Spongia (Spongia) officinalis</i> Linnaeus, 1759					+		+	+	AM	
72.	<i>Spongia (Spongia) virgultosa</i> (Schmidt, 1868)				+	+	+	+	+	AM	
73.	<i>Spongia (Spongia) zimocca</i> Schmidt, 1862					+			+	E	
Thorectidae Bergquist, 1978											
	<i>Cacospongia</i> Schmidt, 1862										
74.	<i>Cacospongia mollior</i> Schmidt, 1862				+	+				AM	
75.	<i>Cacospongia proficiens</i> Pulitzer-Finali & Pronzato, 1980						+			E	R2
	<i>Fasciospongia</i> Burton, 1934										
76.	<i>Fasciospongia cavernosa</i> (Schmidt, 1862)						+			AM	
Verongida Bergquist, 1978											
Aplysinidae Carter, 1875											
	<i>Aplysina</i> Nardo, 1834										
77.	<i>Aplysina aerophoba</i> Nardo, 1833	+	+	+	+					AM	P

Comparative analysis revealed high values of the similarity index: Falco vs. Bisbe ca. 83%, Galatea vs Falco ca. 73%, and Galatea vs Bisbe ca. 69% (Figure 2). Boring and encrusting sponges were common (Table I). Regarding massive horny sponges, all five Mediterranean species of the genus *Spongia* Linnaeus (1759) were recorded in the caves, e.g. *Spongia (Spongia) lamella* (Schulze, 1879) and *Spongia (Spongia) officinalis* Linnaeus (1759) were shared by all three caves.

Taxonomic richness in *Posidonia* meadows

In all, 45 species, plus one taxon identified at the genus level, 33 genera, 26 families and 14 orders were recorded in *Posidonia* meadows. Mediterranean endemics accounted for nine species (endemicity 20%). Only four species were shared by the five meadows sampled, i.e. *Spirastrella cunctatrix* (Schmidt, 1868), *Chondrilla nucula* (Schmidt, 1862), *Crambe crambe* (Schmidt, 1862) and *Ircinia variabilis* (Schmidt, 1862). Similarity index values ranged from 25% to 63% among the meadows sampled (Figure 3). Some sponge species preferentially colonised rhizomes, e.g. *Cacospongia mollior* (Schmidt, 1862), *C. crambe*, *Dysidea fragilis* (Montagu, 1814),

Hippospongia communis (Lamarck, 1814), *Spongia (Spongia) virgultosa* (Schmidt, 1868), *S. officinalis*, *Tethya aurantium* (Pallas, 1766) and *Tethya citrina* (Sarà & Melone, 1965). Others were found mainly in intermatte areas with rocky substrates, e.g. *Ircinia retidermata* (Pulitzer-Finali & Pronzato, 1981), *I. variabilis* and *Pachychalina rustica* (Schmidt, 1868). Only *Hymedesmia (Hymedesmia) pansa* (Bowerbank, 1882) was found on leaves.

Comparison of taxonomic richness

In total, 69 species, plus eight taxa identified at the genus level, belonging to 52 genera, 37 families, 20 orders and three classes, form the updated checklist of Porifera from the two MPAs (Table I). The index of similarity between *Posidonia* meadows and caves was ca. 57% on the basis of 27 shared species (Figure 4). ANOSIM showed significant differences in the sponge composition of the two habitats ($R = 0.703$; $p < 0.05$), and nMDS data ordination revealed a clear separation of habitats, with intragroup differences being fewer in caves than in *Posidonia* meadows (Figure 5).

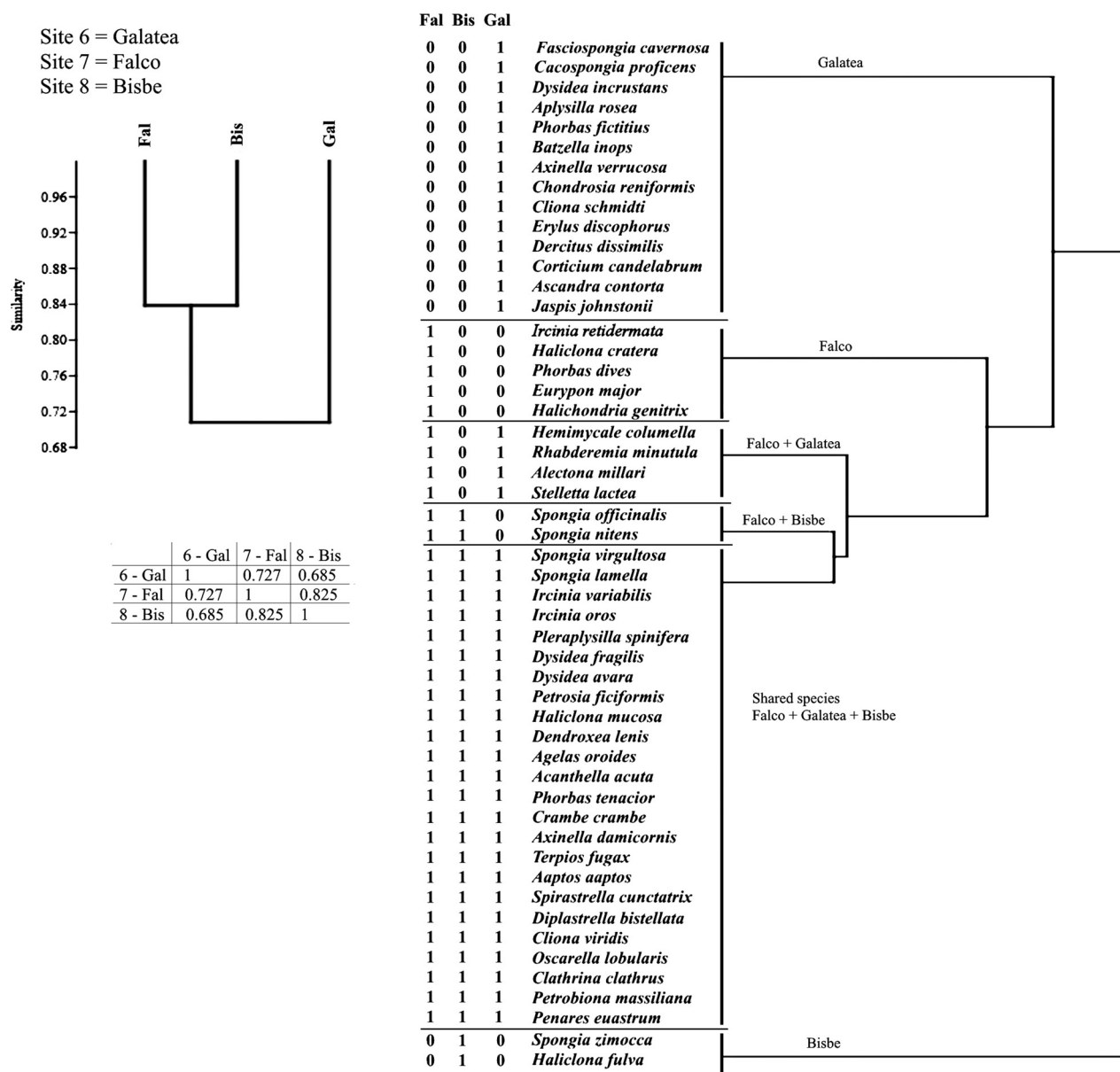


Figure 2. Sponge fauna of Bisbe, Falco and Galatea caves at the Capo Caccia–Isola Piana Marine Protected Area (MPA). Similarity (Bray–Curtis) values among the three caves sharing ca. 50% of species, with very high values (> 83) between Bisbe and Falco. Taxa identified at the genus level are not considered.

Protected species and rare species

The survey highlighted the presence of five sponge species protected by the (Specially Protected Areas/Biological Diversity in the Mediterranean) SPA/BIO protocol of the Barcelona Convention (Pronzato 2003; Relini & Tunesi 2009). Caves of Capo Caccia–Isola Piana MPA harboured *Petrobiona massiliiana* (Vacelet & Lévi, 1958), *S. lamella*, *S. officinalis* and *S. zimocca* (Schmidt, 1862), while *T. aurantium*, *S. lamella*, *S. officinalis* and *S. zimocca*

were found in the *Posidonia* meadows in the Asinara Island MPA.

Rare Mediterranean sponge species were also found, i.e. *Cacospongia proficiens* (Pulitzer-Finali & Pronzato, 1980) (two known reports), *Dercitus* (*Stoebea*) *dissimilis* (Sarà, 1959) (three known reports), *I. retidermata* (three known reports), *P. rustica* (seven known reports) and *Clathrina rubra* (Sarà, 1958) (eight known reports). Two of these, *C. proficiens* and *C. rubra*, had previously been recorded in caves (Pansini et al. 2011).

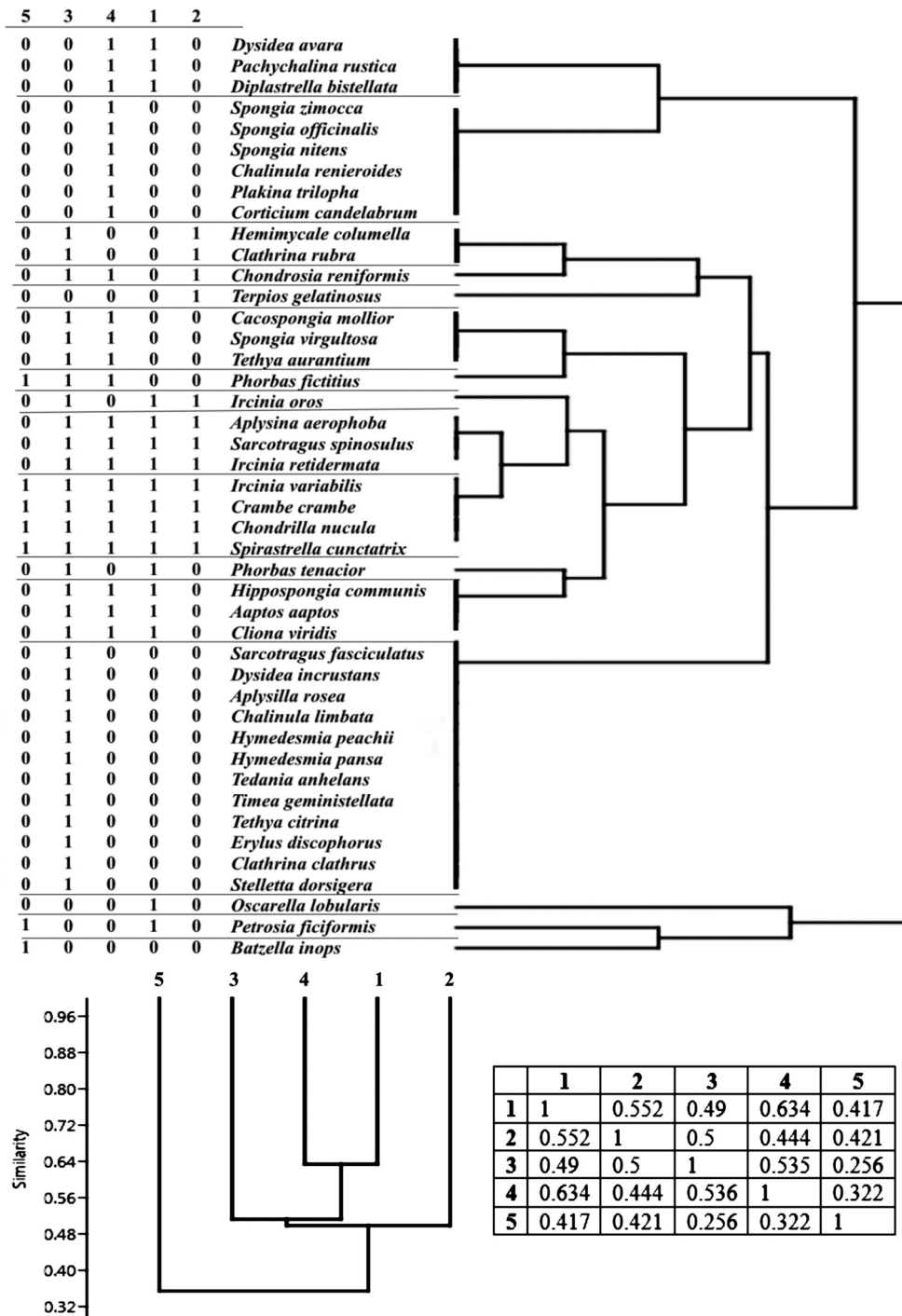


Figure 3. Sponge fauna of five *Posidonia* meadows at the Asinara Marine Protected Area (MPA). Similarity (Bray-Curtis) values range from approximately 20% to 60%. Only four species are shared by all sites (ca. 11%). Taxa identified at the genus level are not considered.

Discussion and conclusions

The faunistic census revealed a remarkably rich assemblage in the two Sardinian MPAs, i.e. over 10% of the entire Mediterranean Porifera diversity

(ca. 720 species, Pronzato & Bertolino's unpublished database) despite the very few sampling sites and low sampling effort. The several new records suggest that species richness is underestimated in Sardinia seas.



Figure 4. Sponge fauna of caves vs. *Posidonia* meadows in two north-west Sardinian Marine Protected Areas (MPAs). Similarity index between meadows and caves is ca. 57% on the basis of 27 shared species (< 40%). Taxa identified at the genus level are not considered.

Seagrass meadows and caves are contrasting biotopes, which pose divergent environmental challenges for Porifera. Data, as we expected, show significant differences in sponge community composition between *Posidonia* meadows and marine caves. The high heterogeneity and species variability in the

meadows (nMDS test) indicates that the intermatte rocky substrate and leaves are suitable for photophilous sponge species, whereas the quite stable rhizome level, together with the shaded areas of boulders scattered in the intermatte, favours sciaphilous species.

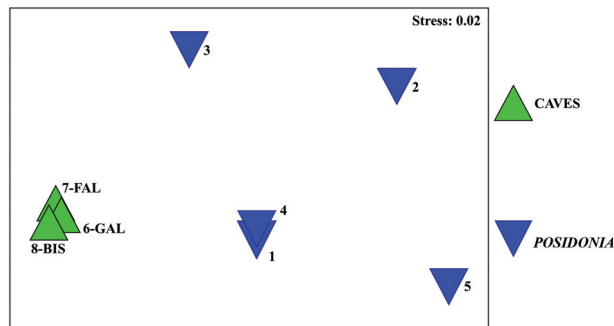


Figure 5. Diverging species composition of Porifera in cave vs. *Posidonia* meadows by non-metric multidimensional scaling (nMDS) data ordination (sampling sites; presence/absence of sponge species). Intragroup differences were smaller in caves (highest homogeneity) than in seagrass meadows, the latter characterised by the highest species diversity. Numbers refer to the eight sampling sites in Figure 1.

With regard to the Western Mediterranean *Posidonia* meadows, Asinara hosts 45 sponge taxa, whereas Pansini and Pronzato (1985) reported 75 species from Lacco Ameno (Ischia Island) and 42 from Prelo (Ligurian Sea). These discontinuities in Porifera distribution appear to be related to local environmental factors, such as sanding and sedimentation, rather than to depth (see Pansini & Pronzato 1985). In the Asinara MPA, data confirm that scattered rocky substrates of intermatte areas offer a stable substratum for sponges. Rhizomes are less stable, particularly those at the margins of mattes; indeed, they are damaged during storms or by anchorage and fishing gears as indicated by the frequent stranding of rhizomes with settled sponges along the entire Sardinian coasts (Manconi et al. in prep). By contrast, leaves are suitable for the settlement of only a few species, as they constitute an unstable, deciduous, smooth, short-lived substrate, and are more exposed to wave stress according to Pansini and Pronzato (1982a, 1985; but see also Piazzini et al. 2016). The variable environmental conditions in the five Asinara sites could explain the scant homogeneity of sponge assemblages with only five shared species in all sites (similarity index 25% to 63%).

Concerning Mediterranean marine caves, it is well known that they are hotspots of sponge diversity (e.g. Cadeddu 2012; Gerovasileiou & Voultsiadou 2012; Manconi et al. 2013; Gerovasileiou et al. 2015; Dimarchopoulou et al. 2018), with over 300 documented species, and display similar values of species richness to the coralligenous biotope, in which over 300 species have so far been documented (see Bertolino et al. 2013; Longo et al. 2017).

Punta Giglio caves host 59 sponge species, while 32 species inhabit Mago Cave at Ischia Island (Cinelli et al. 1977) and 52 species have been recorded at Mitigliano Cave along the Sorrentine Peninsula (Pansini & Pronzato 1982b). By contrast, 78 cave-dwelling species have been recorded in the entire Balearic Sea, and a higher value of richness (161 species) has been reported in the Gulf of the Lion (see Cadeddu 2012). On considering only species richness, the present data are in agreement with previous papers on the Western Mediterranean.

The diversity of sponges in the three Sardinian caves matches the results of previous Mediterranean studies (e.g. Cinelli et al. 1977; Pansini & Pronzato 1982b; Dimarchopoulou et al. 2018). Until now, cave-dwelling Porifera from Sardinia have been cited in a few surveys of benthos (Bianchi & Morri 1994; Cadeddu 2012) and in descriptions of new and/or rare species from dark areas of these cryptic habitats (Manconi et al. 2006, 2009; Manconi & Serusi 2008; Manconi 2011). The rocky calcareous cliffs of Capo Caccia–Isola Piana MPA are known to host more than 200 (estimated by local speleologists) karstic caves, only ca. 50 of which have been mapped, despite the high interest of speleo-divers in this area during the last 50 years (see Chessa et al. 1999). Unfortunately, however, the notable effort in speleological explorations and geo-morphological surveys on submerged marine caves has not been matched by further investigations of biodiversity.

Differences in the taxonomic composition of sponge fauna are clearly evident on comparing *Posidonia* meadows with caves in the two MPAs investigated, although the unexpected low value of dissimilarity (43%) may partly be explained by the presence of sciaphilic sponges in shaded microhabitats of boulders scattered in the intermatte meadows. Moreover, in the caves presently studied, the absence of new species or stygobiont species, such as those reported from a few other Sardinian caves, seems to be related both to the strict affinity of the extremely rare lithistids for restricted areas in totally dark cave zones of the Capo Caccia–Punta Giglio karst (Manconi et al. 2006; Manconi & Serusi 2008) and to the extreme anchialine condition in a Tyrrhenian estuary cave of the Dorgali karst (Melis et al. 2016).

The cave-dwelling sponge fauna displays notable homogeneity (24 species shared by three caves), while *Posidonia* meadows (four species shared by five sampling sites) are considerably heterogeneous.

The ability of sponges to disperse and settle among neighbouring caves (connectivity) is suggested by the ca. 40% of shared species in the caves investigated.

Moreover, comparison between the two biotopes, which are presumed to be totally different, revealed

that shaded micro-habitats (e.g. under boulders) in intermatte meadows harbour sciaphilic sponge species shared with caves, suggesting that the meadows may act as a reservoir supporting connectivity among sponge assemblages of other coastal biotopes. This could be particularly true of the extensive continuous meadows of *P. oceanica* along the Sardinian coast, particularly Asinara Island, which are considered to be some of the most pristine along the Italian coastline, even though few regressive areas are evident (see Telesca et al. 2015).

The heterogeneous composition and structure of sponge fauna in the meadows at Asinara confirm that this biotope hosting both sciaphilous and photophilous species is less selective than caves. By contrast, only sciaphilous sponges are likely to be found in dark submerged caves, except for the entrance zone when it is large and in shallow water.

From a taxonomic and conservation point of view, several internationally protected species (six of a total of 15) and five rare species (less than 10 records in the Mediterranean Sea) are harboured in the two MPAs. In particular, the surveys in caves yielded the third record of *Cacospongia proficiens* (the first in the western Mediterranean Sea). *Dercitus* (*Stoebea*) *dissimilis*, which is also a very rare species (see Rwm et al. 2018), was recorded in the karstic caves.

Present data increase sponge fauna diversity in the eastern Algero-Provençal Basin although inventories of Sardinian cave-dwelling sponge species have recently been expanded (Manconi et al. 2006, 2009, 2013; Manconi & Serusi 2008; Manconi 2011; Cadeddu 2012; Melis et al. 2016). In conclusion, the diversity of Porifera in *Posidonia* meadows and submerged karstic caves of the Mediterranean Sea confirms that these two biotopes constitute one of the most important natural heritage and biodiversity hotspots of the Mediterranean Sea, together with coralligenous communities (Ballesteros 2006; Relini & Giaccone 2009). The new data set will constitute a basis for future long-term investigations and comparative analyses supporting further conservation efforts.

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Disclosure statement

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